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(71) Applicant: SOLIGEN, INC. [US/US]; 19408 Londelius Street, Northridge, CA 91324 (US).

(72) Inventors: GNESSIN, Amir; 22500-6 Jeffrey Mark Court, Chatsworth, CA 91311 (US). BHARATHAN, Sanmuggarajah; 18414 Vincennes Street #106, Northridge, CA 91325 (US). MIZRA, Dror; 2400 Beverly Avenue #12, Santa Monica, CA 90405 (US). COHEN, Adam, Lloyd; 10717 Wilshire Boulevard #802, Los Angeles, CA 90024 (US).

(74) Agents: GANS, Bernard, R. et al.; Poms, Smith, Lande & Rose, 2029 Century Park East, Suite 3800, Los Angeles, CA 90067 (US).

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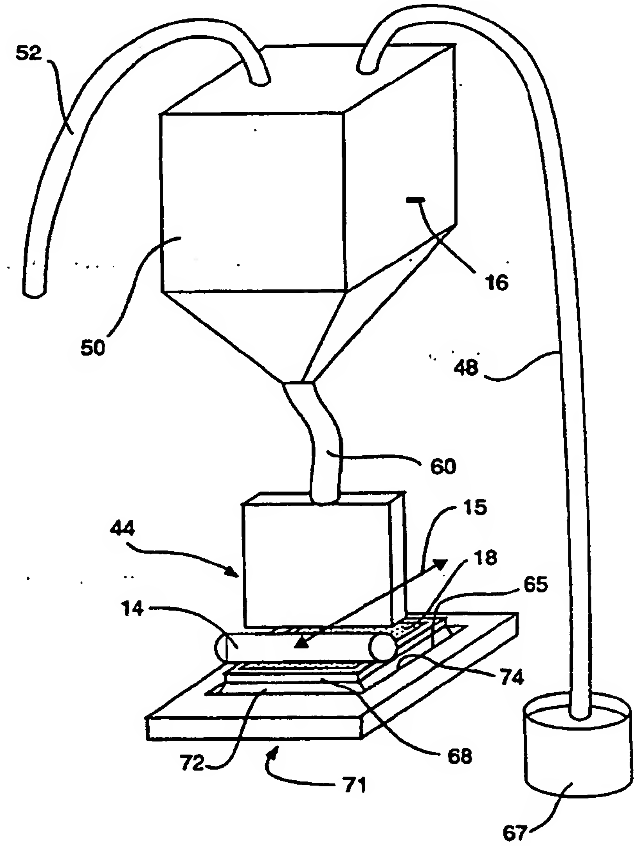
(54) Title: POWDER HANDLING APPARATUS FOR ADDITIVE FABRICATION EQUIPMENT

(57) Abstract

An apparatus used for powder handling in a layerwise additive fabrication process such as three-dimensional printing (3DP) or selective laser sintering (SLS), comprising apparatus for dispensing bulk powder (44) so that it can readily be spread into a series of thin layers, for conveying bulk powder so as to fill the dispensing apparatus (44), and further for collecting excess dispensed powder not incorporated into these layers. The dispenser (44) functions by applying a high-frequency vibration to an enclosure (29) filled with powder, whose bottom face (45) is perforated. It is filled by a hopper (50) above which is itself filled from a powder supply container (67) by the use of a vacuum. Finally, excess powder falls into a gutter and removed from it by a vacuum cleaner after a seal (74) on the gutter (71) has closed.



POWDER HANDLING APPARATUS FOR ADDITIVE FABRICATION EQUIPMENT

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an apparatus for powder handling used in conjunction with a layerwise additive fabrication process, such as three dimensional printing (3DP) or selective laser sintering (SLS). More precisely, the present invention relates to an apparatus for dispensing bulk powder (e.g., ceramic, metal, and plastic) so that it can readily be spread into a series of thin layers, for conveying bulk powder so as to fill the dispensing apparatus, and further, for collecting excess dispensed powder not incorporated into these layers.

2. Description of the Prior Art and Related Information

Layerwise additive fabrication processes, which create three-dimensional objects from geometrical data one thin layer at a time, have become widely used in the last few years. More precisely, layerwise additive fabrication is a fabrication process in which a physical, three-dimensional object is formed by the layer-by-layer addition of material, the process being driven by a geometrical description of the object. In general, such processes, driven by computer aided design (CAD) data, offer reduced time-to-market and cost savings for manufacturers, by providing visualization models, and in some cases, functional prototype parts through a quick, highly-automated process.

Two additive fabrication processes currently in use need powdered materials, and require that these powders be spread to form successive thin layers; these processes are, namely, Three Dimensional Printing (3DP) and Selective Laser Sintering (SLS). In the case of 3DP, a second material, in the form of a liquid binder, is applied selectively to the powder to bond the grains together. With SLS, no additional material is used, but rather, the grains are sintered or melted through the action of heat

(normally provided by a laser) and thereby converted to a solid mass.

Objects made with 3DP are constructed from a plurality (typically hundreds) of very thin layers. Specifically, the fabrication process involves two steps per layer. First, powder is deposited and spread to form a thin layer by a roller mechanism. Second, the data representing the object geometry is processed to yield a 2-dimensional cross section, and this cross section is then "printed" onto the layer by selectively depositing liquid binder, typically using an inkjet-style of printhead. The binder penetrates the pores between the powder particles and binds them together into a rigid structure. Having thus formed a single layer, the object geometry is cross-sectioned again at a slightly higher position, and the process is repeated until all layers are formed.

By using ceramic powders and binders very similar to those traditionally used by investment casting (also known as "lost wax"), foundries can employ 3DP to directly fabricate a ceramic shell (i.e., a mold). This shell can then be poured with molten metal, producing a functional metal cast part. This process is known as Direct Shell Production Casting (DSPC). The shell may contain integral ceramic cores, allowing hollow metal parts to be produced. Virtually any molten metal can be cast in DSPC shells.

DSPC can eliminate most of the labor-intensive and time-consuming steps of the traditional investment casting process. To be sure, many labor and time-intensive steps found with other foundry processes, such as sand casting, could also be eliminated. Compared with investment casting, DSPC bypasses the need for design and manufacturing of wax and core tooling, wax and core molding, wax assembly, shell dipping and drying, and wax removal. Normally, these conventional procedures delay delivery of the first sample casting by as much as 18 months.

With DSPC, metal can be poured within days after a CAD design for the desired metal part is completed. After pouring, parts need only to be finished and inspected before they can be shipped to the designer. Metal tooling including dies used in

the injection molding of plastics, can also be cast in DSPC shells with reduced cost and lead time.

DSPC can have a tremendous impact on manufacturing companies by reducing development time for new products, by enabling flexible manufacture of products in small quantities at acceptable cost, and by exploding the traditional relationship between part cost and part complexity. As a result, the cost of producing a shell to cast a complex shape is virtually the same as for a simple one.

A system for DSPC consists of two pieces of equipment: a Shell Design Unit (SDU) and a Shell Production Unit (SPU). The SDU is a powerful graphics workstation running specialized software that allows the geometry of a casting shell to be generated quickly from a CAD file of the desired part. The SPU then automatically fabricates the shell from raw materials.

Producing a metal part with DSPC is in some ways similar to producing it with investment casting. As with all casting processes, a gating or "plumbing" system must be created to distribute molten metal from a central pouring cup to the cavity or cavities of the casting mold. With investment casting, the mold cavities and the conduits through which metal flows are produced by using a complex wax structure known as a "tree" or cluster. Each tree is coated with a thick shell of ceramic, then melted and poured out to provide an air space that can be filled with metal. With DSPC, no physical wax is used. Rather, the tree is constructed only one time on the screen of the SDU, appearing in simulated "wax." The SDU then automatically generates the mold geometry.

The Shell Production Unit (SPU) includes a bin which contains powder. The bin is fitted with a piston which can be moved vertically in precise increments under computer control. Above the piston is a hopper containing ceramic powder such as alumina. A roller located at the upper edge of the bin can be translated across the bin above the piston.

Also above the piston is a printhead similar to that used by inkjet printers. Typically, the printhead is supplied with a liquid binder commonly made of a formula based on colloidal

silica. The printhead can be moved across the piston surface under computer control, ejecting tiny drops of binder toward the piston in a pattern which corresponds to the layer cross section.

The process of producing a shell for Direct Shell Production Casting is shown in Fig. 1. A CAD file of the part is loaded into the SDU via floppy disk, for example, and is converted into a shell model. This is then transferred by local area network to the SPU, which generates the casting shell.

Fig. 2 shows the detailed steps of the DSPC process. In Fig. 2(a) the part is designed on CAD software and output in an appropriate file format. In Fig. 2(b), a shell geometry is created using the SDU, based on the input part file. The SDU then outputs an electronic model of the ceramic shell, complete with cores to form the hollows within the part. Fig. 2(c) shows the fabrication process in progress, wherein ceramic powder is dispensed and spread into a thin layer within a bin. In Fig. 2(d), after computing a cross section of the shell geometry, the computer controls a printhead to deposit liquid binder in regions of the layer corresponding to the cross-section. In Fig. 2(e), the entire shell has been formed after additional cycles of spreading layers and depositing binder. In Fig. 2(f), the shell is removed from the bin and all powder has been removed from the shell. In Fig. 2(g), the shell has been fired and filled with molten metal. In Fig. 2(h), the shell has been broken away, and the cores have been dissolved in caustic chemicals and the gating has been cut and ground off, resulting in the desired metal part as originally designed. The mechanical properties of this part are virtually identical to those produced using conventional investment casting methods.

The handling of powder in an additive fabrication system, such as the DSPC system described above, represents several significant inventive challenges, such as:

How to accurately, repeatably, and conveniently transfer and dispense a small (e.g., a few dozen grams), known quantity of fine (e.g., 20-30 microns) highly-abrasive powder to the bin and spreading mechanism, given that such powder is supplied typically in large drums weighing approximately 400 kg;

How to perform all powder handling operations with minimal transfer of fine abrasive airborne particles to sensitive areas of the equipment (e.g., bearings) and minimal contamination of the surrounding air (a potential safety hazard);

How to dispense the powder quickly and with high uniformity along the length of the spreading mechanism (about equal to the bin width), while allowing for future bin widths of 1-2 meters;

How to dispense powder on demand, without interrupting operation of the machine, while allowing for potential futur bins having capacities of one cubic meter or greater;

How to ensure that the spread layer has similar properties (e.g., particle density, particle size distribution, particle orientation) throughout;

How to reliably and efficiently collect excess dispensed powder for re-use, without any accumulation around the bin, and allowing for potentially very large volumes; and

How to manufacture all powder handling apparatus easily and at low cost.

There are conventional approaches that address powder handling needs of an additive fabrication system. For example, U.S. Patent No. 5,132,143 to Deckard, U.S. Patent No. 5,252,264 to Forderhase et al., and the "Alpha" DSPC system manufactured by Soligen, Inc.

Deckard discloses an early version of a powder handling system for SLS, later superseded by the system described in Forderhase, which is substantially that used commercially in current equipment.

Forderhase teaches a powder handling system having two rectangular powder supply cartridges, each of which is provided with a sliding piston serving to extrude powder at the open upper end. The two cartridges are arranged on opposite sides of a circular piston sliding within a cylinder. The object is fabricated by solidifying the powder delivered into this cylinder or bin. To form a first layer, a supply cartridge extrudes powder to a certain height above a reference surface. A roller mechanism then sweeps the extruded powder across the surface and towards a receiving cartridge on the opposite side of the

cylinder. Since the central piston has previously been lowered, part of the swept powder is retained in the cylinder, forming a thin layer above previously-formed layers. Powder not so retained is swept into the receiving cartridge, whose piston has lowered to accommodate it. The process typically is reversed to generate the second layer, with the receiving cartridge becoming the supply cartridge and vice-versa. On the third layer, the process proceeds as per the first layer, and so on.

Forderhase has several disadvantages, however. First, because of the need for cartridges adjacent to the cylinder, and because of the need for the spreading mechanism to travel fully across both powder cartridges, Forderhase requires a great deal of space and is difficult to scale up. Second, because of the long travel of the spreading mechanism, and because the cartridge must wait for the mechanism to cross it before the piston rises to extrude powder, the approach is limited in speed.

Third, because of the relatively small capacity of the cartridges, the Forderhase approach may require manual interchange of the cartridges while the machine is running, requiring an operator to attend the machine. This necessitates manual labor, and, assuming the machine can function temporarily with one cartridge, interrupting the normal alternating cartridge sequence. Fourth, the small capacity makes scale-up to a larger bin more difficult.

Fifth, the mechanical operation of spreading a layer may introduce changes in the powder which affect its performance. For example, a powder whose particles are somewhat tacky (e.g., wax) may tend to form agglomerates due to spreading, while an especially friable powder (e.g., some ceramics) may tend to break into smaller particles. These changes in powder properties may affect, for example, strength, accuracy, and surface finish of the fabricated object. Additionally, powder may become contaminated by material released by the spreading mechanism (e.g., with abrasive powder) or by pickup of secondary material (e.g., binder or binder/powder agglomerates) from the previous layer. The Forderhase approach continuously mixes such altered and/or contaminated, previously-spread powder, with virgin powder in the

supply cartridges (presumed to be optimized for producing quality objects), and the degree of mixing and contamination of virgin powder becomes increasing worse as more layers are spread.

Sixth, since all powder is supplied at the start of travel, the amount of powder swept by the roller mechanism decreases as the mechanism travels across the cylinder, as more and more powder is incorporated into the layer, yet the properties of the spread layer are to some extent a function of the quantity of powder acted upon by the spreading mechanism while spreading. Therefore, the Forderhase approach cannot provide layers which are perfectly homogeneous, and variations in, for example, powder density, size distribution, and grain orientation are possible across the layer. These variations may affect, for example, the strength, accuracy and surface finish of the fabricated object.

Seventh, possible changes in the nature of the powder due to spreading, mentioned above, also cannot be avoided with Forderhase. Therefore, the powder forming the layer at one end of travel may be different than that at the other end.

Eighth, unless a powder supplier fills the cartridges described by Forderhase, they must be filled by transferring powder from a large container. This is an expensive proposition for the machine owner, since packaging costs are proportionately higher for small quantities than large ones. The means available to the machine operator for effecting this transfer, for example, manual transfer with a scoop, are tedious and messy, and also tend to fill the air with fine particles which are a respiratory hazard. The contribution of the fine particles to the spread layer may also be required, e.g., to improve strength, accuracy, or surface finish. The cartridge filling problems are exacerbated due to the small volume of the cartridges, since multiple cartridges may be needed to complete the fabrication of a tall object.

Ninth, in the same way that the cartridges must be filled prior to use, they must be emptied by the operator after use unless they are shipped back to a factory for emptying and refilling. This is again an expensive proposition. This

process, once again, is tedious, messy, potentially hazardous, and may harm powder reusability.

Tenth, the Forderhase approach suffers from several complexities related to accurate and consistent metering of powder; that is, accurately and consistently delivering the correct quantity of powder to the roller mechanism for all layers, which require a powder surface sensing device to resolve. For example, the cartridges always are filled to the same degree before installation, the correct initial position of the cartridge piston, which places the powder surface at approximately the correct level, cannot be determined. Also, if the cartridge pistons were programmed to execute a fixed, open-loop movement with each layer, and the amount of excess powder swept into a cartridge is less or greater than that anticipated, the amount of powder delivered to the spreader mechanism would cumulatively decrease or increase, respectively. Therefore, since the amount of excess powder is very difficult to determine precisely without trial and error, and differs according to the powder used and may vary during operation due to losses, variable shrinkage of the material within the cylinder, etc., the only way to ensure accurate and repeatable metering is using a complex closed-loop servo system in which the cartridge piston movements are determined by a fairly accurate measurement of the position of the powder surface. Of course, for this to work properly, the powder redistributor mentioned by Forderhase as an option, is in fact a necessity, since otherwise the uneven powder surface could not be relied on as an indicator of the true volume in the cartridge. This redistributor must also achieve a reasonably flat layer for good results. Failure to correctly and accurately meter enough powder with the Forderhase approach can produce cumulatively worsening effects on the fabricated object, such as weakness, distortion, voids, and surface roughness, and too much powder may well overwhelm the apparatus and cause mechanical failure.

Eleventh, according to Forderhase, spread powder which migrates past the ends of the roller during spreading is not collected for re-use, and unless provision is made, may accumu-

late in undesired places since there is nowhere for it to go. Furthermore, when changing over the machine from one powder to another, this residual powder must be dealt with.

Lastly, if a need arises to fabricate an object from more than a single type of powder, the Forderhase approach would be extremely cumbersome to implement, requiring the shutdown of the machine, the replacement of both cartridges, and the clean up of any residual powder.

The "Alpha", or first-generation DSPC system manufactured by Soligen, Inc., overcomes several of the disadvantages of the Forderhase approach to powder handling. The Alpha powder handling system is depicted shown in Fig. 3. ~~A hopper 50 is~~ loaded manually with powder. Pivot 16 allows the hopper to rotate to follow the motion of powder dispensing apparatus (PDA) 12 forward and backward across bin 68. Hopper 50 may include an associated vibrator (not shown) to prevent bridging of powder within. Powder is fed by gravity down flexible outlet hose 60 (the flexing of hose 60 while PDA 12 moves avoids potential bridging of the powder in hose 60) to PDA 12. PDA 12 comprises an enclosure having an upper surface through which powder enters, and a perforated lower surface. The perforations are small enough so that little if any powder exits the enclosure under normal conditions, due to a tendency of the limited-flowability powder to bridge the perforations. PDA 12 also comprises an impact mechanism consisting of two solenoid-operated hammers which strike blocks mounted on the enclosure. Impact of the hammers on the blocks causes some movement of the powder with respect to the apertures, with the result that powder is discharged into bin 68 in front of spreading mechanism 14 comprising a roller. PDA 12 and mechanism 14 are both fastened to a gantry (not shown) which moves them across the bin in the directions shown by arrow 15. After discharging a small amount of powder to "prime" the roller, a powder layer 18 is formed by moving the gantry to the rear while powder is discharged from PDA 12 into th path of mechanism 14. Optionally, all of the powder may be discharged prior to the movement. Powder pushed over the rim of bin 68 falls onto the tilted walls of powder collection

gutter 11 surrounding bin 68, sliding and being sucked down the walls by a vacuum cleaner (not shown) into gap 13. Powder entering gap 13 is withdrawn from gutter 11 and enters the canister of the vacuum cleaner, from which it can be recovered.

The Alpha powder handling benefits from several improvements over Forderhase. First, because powder is stored above the bin rather than at both sides, and because the powder spreading gantry need only traverse the bin rather than the bin plus two cartridges, the footprint of the associated components is smaller and the layer generating speed greater. Second, because of the shorter gantry stroke and the ability to make the hopper arbitrarily large in principle, the Alpha approach allows considerable room for scale-up to larger bins.

Third, because the hopper can be made as large as needed whereas enlargement of Forderhase's cartridges is more restricted, it can supply all the powder needed for to fabricate an object of maximum height without interruption or manual intervention.

Fourth, because the PDA of the Alpha approach can dispense virgin powder in front of the spreading mechanism as it moves, the amount of powder swept by the roller mechanism can be held constant as the mechanism travels across the cylinder, and the majority of the powder incorporated into the layer can be virgin powder.

Fifth, if desired for some reason (e.g., to compensate for some other non-uniformity), the rate of powder discharge, and thus the amount of powder in the path of the roller, can be modulated across the layer using the Alpha approach, which cannot be done according to the Forderhase device.

Sixth, because powder once spread is collected by the gutter, and only powder from the hopper is delivered to the roller, there is no mixing of virgin and used powder in the bin, as with Forderhase. Seventh, because all excess powder is drawn into the canister of a vacuum cleaner, which can be large (e.g., a 55-gallon drum), the laborious, time-consuming, and hazardous transfer of powder from small cartridges is avoided. Eighth, because excess powder is never added back to the supply contain-

er, and because, even if it were, the Alpha's PDA would still meter powder at a constant but adjustable rate, there is no need for a powder level sensor or any closed-loop controller requiring such a sensor's input.

Ninth, because of the need for sophisticated, interchangeable powder cartridges, which must have close-fitting pistons to avoid powder leakage, and three (not just one) independent motion-controlled stages, the Forderhase approach is complex, costly and difficult to manufacture. The Alpha approach provides powder to the spreading mechanism by a relatively simple set of low-tolerance components such as the powder dispensing apparatus and hopper.

Tenth, because powder migrating to the ends of the spreading roller falls into the collection gutter and is removed, rather than left behind on the top of the plate, the Alpha approach is less messy.

Eleventh, because the Alpha's PDA is small and, along with the hopper, forms a self-contained delivery system, it could be fairly easily interchanged with another similar system containing a different powder. Alternatively, several systems could be integrated into a machine for simultaneous or sequential use, the powder dispensing apparati being mounted one behind the other on the moving gantry. Such a system would enable an easy changeover of powder as often as once per layer or even, if desired, within a single layer. Of course, since all residual powder would be collected by the same gutter, it might not be separable for reuse.

The Alpha approach has some limitations. First, the PDA has a low rate of discharge; this limits the speed of spreading layers, and can become the bottleneck in achieving higher machine throughput. Second, running the solenoid-operated hammers for an extended period can cause the solenoids to overheat, reducing their impact force and even causing misfiring and resulting non-uniformity in the dispensed powder.

Third, the PDA's solenoid-driven hammers have a tendency to stick and misfire or impact with less force, generally due to contamination by airborne abrasive powder. This causes less

powder to be delivered to the spreading mechanism, producing an incomplete or loosely-packed powder layer.

Fourth, both the frequency and the impact force of the PDA hammers affect discharge rate and uniformity, making the PDA difficult to tune for optimal throughput and uniformity. This is especially annoying given that the tuning of a PDA is a function of the powder type within. Exacerbating this is the fact that small differences from one PDA to the next require each one to be tuned individually by trial and error, and the fact that frequency and impact force are coupled, interdependent parameters. Changes to the powder type require retuning.

Fifth, high uniformity of powder delivery (i.e., consistency of discharge rate from place to place) along the length of the PDA is difficult to achieve, and is sensitive to a variety of perturbing factors through extended use.

Sixth, the impact of the PDA hammers produces a very loud, annoying, and startling sound.

Seventh, the hopper must be filled by climbing a ladder or the machine frame to reach its brim, then pouring powder from a heavy bucket or transferring powder using a scoop. The former technique produces a great deal of hazardous, airborne powder and risks injury due to the weight of the bucket, while the latter technique is very slow and laborious. Both techniques carry risk of operator injury due to falling and may require several trips up and down to completely fill the hopper.

Eighth, if the hopper is not sufficiently filled, the PDA may run out of powder while fabricating the object, causing the object to be incomplete, and possibly causing damage to the machine.

Ninth, if the width of the gutter gap is made too small, the powder tends to bridge across the gap and not be sucked in, building up a large mound over time. On the other hand, if the gap is made too large, the gutter is "leaky" and the local air velocity is inadequate to carry away powder that has entered the gutter. This difficulty in adjusting the width of the gutter gap just right is compounded by the fact that the amount of powder which falls into the gutter can vary dramatically from location

to location. Furthermore, this distribution can change with various spreading parameters and with powder type.

Tenth, because of the need to generate high air velocity within an inefficient "leaky" system, a high-powered, expensive, very noisy, and short-lived vacuum blower must be used in an attempt to clear the gutter of powder. Tenth, because of the inefficient design, the gutter must be plumbed in several locations (e.g., all four corners) and the resulting set of hoses properly routed and joined into to a common hose connected to the vacuum cleaner.

Eleventh, if contaminated (e.g., by liquid binder), the Alpha gutter is difficult to clean. The small gap restricts access and normally forces disassembly of the gutter, a time-consuming process.

Based on the foregoing, there is presently a need for an improved apparatus and method for powder additive processing.

SUMMARY OF THE INVENTION

The present invention is directed to an apparatus and method of additive fabrication processes which use powdered material. An object of the present invention is to overcome the cited disadvantages of the Alpha approach to powder handling, so as to achieve a satisfactory and reliable approach to powder handling having several important advantages over that of Forderhase. These include:

Lower cost.

Greater convenience and ease-of-use.

Reduced operator intervention.

Smaller footprint.

Greater freedom to scale up.

Higher speed and continuous operation.

Improved manufacturability and serviceability.

Avoidance of powder contamination.

Greater layer homogeneity.

Lower generation of airborne particulates.

Lower complexity and higher reliability.

Multiple-powder capability.

The present invention powder handling system includes at least three major improvements. First, a PDA which is vibrated by a new variety of exciter based on counter-rotating masses, and at a much higher frequency than before, resulting in much higher powder discharge rate; continuous, long-term operation without overheating; higher reliability of powder delivery; easier tuning (i.e., optimization); higher uniformity of powder delivery; less noise.

Second, a hopper system which is loaded by vacuum from a supply container, resulting in: no need to climb up and risk injury; convenient filling from ground level; faster filling; less risk of inadequate powder because easy to fill sufficiently.

Third, a gutter which includes a seal which can close the gap through which powder enters, resulting in: no bridging of powder across gap; no need to adjust gap; complete removal of excess powder falling on all sides of bin; a less costly, quieter, longer-life vacuum cleaner blower, allowing the blower to operate continuously to remove airborne fines within the dust chamber; plumbing of the gutter in only one location; easy disassembly for cleaning.

Further objects and advantages of the invention will become apparent from a consideration of the drawings and ensuing description thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows a prior art DSPC process for making a metal part from a CAD design.

Figs. 2(a)-2(h) show the detailed steps of the prior art DSPC process. In Fig. 2(a) the part is designed on CAD software and exported in an appropriate file format. In Fig. 2(b), a shell geometry is created based on the input part file. In Fig. 2(c), showing the fabrication process in progress, ceramic powder is dispensed and spread into a thin layer within a bin. In Fig. 2(d), after computing a cross section of the shell geometry, a printhead deposits liquid binder in regions of the layer corresponding to the cross-s ction. In Fig. 2(e), the entire shell has been formed after additional cycles of spreading layers

and depositing binder. In Fig. 2(f), the shell is removed from the bin and all powder has been removed from the shell. In Fig. 2(g), the shell has been fired and filled with molten metal. In Fig. 2(h), the shell has been broken away, leaving the desired metal part ready for finishing.

Fig. 3 depicts a prior art powder handling approach of the Soligen Alpha DSPC machine.

Fig. 4 depicts the present invention preferred embodiment powder dispensing apparatus, powder filling apparatus, and powder collection apparatus in relationship to one another.

Fig. 5 shows three views of the present invention powder dispensing apparatus showing the major components.

Fig. 6 shows the major components of the present invention powder filling apparatus.

Fig. 7 shows a plan view of the powder collection apparatus' gutter, with two cross-sectional views superimposed.

Fig. 8 shows an enlargement of one of the cross-sectional views of Fig. 6.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is directed to a powder handling system having in a preferred embodiment a PDA which is vibrated by a new variety of exciter based on counter-rotating masses; a hopper system which is loaded by vacuum from a supply container; and a gutter which includes a seal which can close the gap through which powder enters.

Referring now to Fig. 4, a preferred embodiment of the present invention will be described in overview. A hopper 50 is loaded manually with powder. Pivot 16 allows the hopper to rotate to follow the motion of improved powder dispensing apparatus (PDA) 44 forward and backward across bin 68. Hopper 50 may include an associated vibrator (not shown) or other device to prevent bridging of powder within. Powder is sucked from supply container 67 through inlet hose 48 into hopper 50 by vacuum applied to hopper 50 through vacuum cleaner (not shown) via hose 52. Powder is fed by gravity down flexible outlet hose 60 (the flexing of hose 60 while PDA 44 moves avoids potential bridging

of the powder in tube 60) to PDA 44. Powder dispensing apparatus (PDA) 12 comprises an enclosure having an upper surface through which powder enters, and a perforated lower surface. The perforations are small enough so that little if any powder exits the enclosure under normal conditions, due to a tendency of the limited-flowability powder to bridge the perforations. PDA 44 also comprises an excitation mechanism to be described in detail in a later figure. Excitation of the PDA causes movement of the powder with respect to the apertures, with the result that powder is discharged into bin 68 in front of spreading mechanism 14 comprising a roller. PDA 44 and mechanism 14 are both fastened to a gantry (not shown) which moves them across the bin in the direction shown by arrow 15. After discharging a small amount of powder to "prime" the roller, a powder layer 18 is formed by moving the gantry to the rear while powder is discharged from PDA 44 into the path of spreading mechanism 14. Optionally, all of the powder may be discharged prior to the movement. Powder pushed over the rim of bin 68 falls onto inclined guides 72 and into a gap 65 in powder collection gutter 71 surrounding bin 68. Powder entering gap 65 is withdrawn from gutter 71 by a vacuum cleaner (not shown) after closure of gap 65 by an inflatable seal 74, entering the canister of the vacuum cleaner, from which it can be recovered. Note that hose 60 and everything shown below it is housed in an enclosed dust chamber which comprises part of the machine.

Fig. 5 details the preferred embodiment configuration and principle of operation of PDA 44. To the rear plate 32 of enclosure 29 a drive motor 42 is mounted via bracket 43, as well as bearings for eccentric pulleys 20 and tensioning pulley 26. A drive pulley 28 mounted to shaft of motor 42 drives pulleys 20 and 26 through a double-sided timing belt 30, all pulleys rotating with respect to one another in the relative directions indicated by the arrows. Attached to pulleys 20 are eccentric, mutually counter-rotating masses 22 whose centers of gravity are intentionally not coincident with the axes of rotation of pulleys 20. PDA 44 is preferably suspended by leaf springs 40 attached to mounting blocks 38, from the gantry mentioned earlier, to

which blocks 36 are attached. The bottom face of enclosure 29 is covered by a stainless steel mesh 45, held in place by a frame (not shown.) Powder is discharged through mesh 45 when motor 42 is rotated, causing masses 22 to generate an inertial reaction force which is coupled to enclosure 29 first via rear plate 32, then side plates 33, and which therefore vibrates enclosure 29, mesh 45, and the powder inside. Since the masses rotate in opposite directions and are, in all positions, nearly symmetrically oriented about a vertical axis, the horizontal reaction force components are almost cancelled and the vertical reaction force components of the masses 20 are reinforced, resulting in a strong reaction force which is mostly vertically (i.e., the vibration of the PDA is perpendicular to the plane of mesh 45). It is found that if the masses 20 are strictly symmetrical, powder is discharged at a low rate, and with poor uniformity along mesh 45. Therefore, a small degree of asymmetry of masses 20 (causing a small horizontal component force) is typically provided. Either of masses 20 can be rotated in small increments with respect to the other by changing the position of the teeth of either of pulleys 20 with respect to timing belt 30. Belt tension also plays a role; it is found that by keeping a low tension on belt 30 using tensioning pulley 26, better results are obtained.

It is found that the rate of powder discharge is a strong function of the amplitude of vibration, and especially, the frequency of vibration. The PDA components are preferably designed to generate a peak to peak vibration amplitude of the enclosure in the range of 200-600 microns, with the drive motor speed and pulley ratios selected to provide a frequency of vibration in the range of 80-100 Hz. Provision can be made to adjust the vibration amplitude, for example, by adding screws with locking nuts to eccentric masses 20, which can be adjusted in or out to shift the centers of mass of masses 20, respectively decreasing or increasing the inertial reaction force.

The location of pulleys 20 with respect to the rear plate 32 also is found to have a significant effect on the ability to produce a uniform powder discharge along mesh 45. For a rear

plate 32 measuring 400 mm in width, the optimal location of the shafts for pulleys 20 from the plate 32's centerline is 35 to 55 mm.

In practice, the speed of motor rotation, and thus the vibration frequency, is set by the design parameters and is not adjusted. Assuming eccentric masses 22 are also unchanged, the discharge rate of PDA 44 is then well-characterized for a particular powder. Therefore, accurately and consistently dispensing a desired quantity of powder needed to spread a layer becomes a simple matter of controlling the amount of time that PDA 44 is excited (i.e., controlling the on time of motor 42.) Control of this parameter is normally assumed by the machine control computer.

PDA 44 is normally kept filled with powder due a combination of effects: gravity acting on the powder within hose 60, flexing of hose 60, and vibration of the PDA when discharging powder. However, it is found that even when partly-filled (e.g., while running out of powder), the discharge rate from mesh 45 is substantially unchanged.

The front surface of enclosure 29 may be provided with a clear plastic or glass window (not shown) which allows viewing the level of powder within enclosure 29, and may be useful in identifying contaminated powder so that the machine can be halted before such powder becomes used to fabricate the object.

Mesh 45 can be removed by unfastening the frame which attaches it to enclosure 29. Replacement of the mesh may be necessary after very extended periods of use with abrasive powders, due to wear. In addition, changes in discharge rate which occur when changing powders (due to differences in, for example, particle shape or size, or flowability) can be compensated for using a mesh having a different hole size and/or percent open area.

An optional addition to PDA 44 is a cover (not shown) which is arranged to cover the mesh 45, thus preventing the discharge of powder when closed. This cover may be opened and closed by a solenoid, for example. The cover can be used in several ways. First, it can be kept closed when ver the PDA is not intended to

discharge powder, so that any small amounts of powder which manage to pass through the mesh due to random vibrations when motor 42 is off do not fall onto the powder layer below (generally not a problem for one-directional spreading, since such powder would fall in areas for which the cross section is already formed). Second, the cover, if properly shaped, could serve as a temporary reservoir for powder, allowing powder to be discharged at any time during the machine cycle before it is actually needed for layer spreading; this may increase machine throughput in some modes of operation. Third, the cover can be used as a temporary reservoir for powder and provided with a sensor which gauges the quantity of powder contained (for example, by sensing the level of powder within, or preferably, by measuring the weight of the discharged powder using a spring-scale mechanism). If the quantity of powder can be measured in this way, it is not necessary to measure the discharge rate and adjust the excitation time to deliver the desired quantity of powder: the measuring system can itself deactivate motor 42 when the desired quantity has filled the cover, after which the contents of the cover can be emptied before the spreading mechanism.

Ordinarily the pattern of apertures on the lowermost face of the PDA enclosure would be confined to a rectangular area considerably shorter along the direction of travel than perpendicular to it. However, a PDA having other aspect ratios is possible. Indeed, it is possibly in principal to arrange a PDA which is stationary with respect to the bin and large enough to discharge powder over the entire layer at once.

It may be useful to vary the local rate of discharge from the PDA. One example of this is found in the observation that powder closer to the ends of the roller spreading mechanism tends to be lost over the bin walls while spreading, thus it may be advantageous to deposit more powder near the ends of the roller than near its center. Two general methods can be used to control discharge rate locally. In the first, the aperture size is varied, being larger for higher discharge rates and vice-versa. In the second, the aperture size is constant, but the number of

apertures per unit area (or within a region parallel to the direction of PDA travel) is made to vary, such that the more apertures are provided, the greater the discharge rate in this area.

Other approaches to vibrating the PDA with suitable frequencies and amplitudes, different that the one described above, are possible. For example, a rotating eccentric mounted external to the PDA (e.g., on the gantry) might be coupled to the PDA through a linkage. A commercially-available electric or pneumatic vibrator might also be suitable.

Different methods of dispensing powder with the PDA are possible. For example, the powder can all be dispensed near one edge of the bin, before the spreading mechanism has begun to move. Or, for example, the powder can be distributed continuously at a low rate, or in occasional higher-rate bursts, during the spreading operation.

An extension of the powder spreading arrangement shown in Fig. 4 allows for spreading layers bidirectionally. Depending on the architecture of the additive fabrication machine, this approach can increase throughput. For example, in a 3DP machine using a multi-jet printhead array spanning the entire width of the bin, it is advantageous to both spread layers and print them with each back and forth movement of the gantry, in which case the printhead follows behind the PDA and spreading mechanism, which leave a spread powder layer in their wake. A simple means for providing bidirectional spreading is to provide two PDAs, one on each side of powder spreading mechanism 14. Both PDAs can be filled from a common hopper, if desired.

Fig. 6 details the preferred embodiment configuration and principle of operation of hopper 50 and related components. Hopper 50 is supported through pivots 16 by box 62, which is mounted on the top of the machine. Powder in hopper 50 is conducted down hose 60 to PDA 44 as described earlier. Tightly-fitting hopper lid 51 is furnished with two hoses 52 and 48. Hose 52 is coupled to a vacuum cleaner blower 56 through a secondary air filter (e.g., a HEPA filter) 54. Blower 56 is exhausted to room air through (optional) hose 57. The lower end

of hose 48 is inserted into powder supply container 67; this end may be terminated by a double-concentric pickup tube of the sort commonly used to suck powder from containers (the tube is pushed down into the powder.) Within hopper 50 are a group of primary filter elements 58, consisting of a porous, easily cleaned material, and powder level sensors 64 and 66. Not shown is a controller which receives input from sensors 64 and 66 as well as a manual switch, and which controls blower 56.

To fill hopper 50 with powder supplied in container 67, blower 56 is activated, either automatically, due to detection by sensor 64 that the level of powder is low, or manually, due to activation of the controller switch. Blower 56 produces a partial vacuum within hopper 50 by its coupling through hose 52. This vacuum causes powder in container 67 to be sucked into the end of hose 48 and transported up into hopper 50, filling it from the bottom up. A certain amount of powder (particularly fine particulates), rather than settling once inside hopper 50, tends to remain airborne, and is sucked toward primary filter elements 58. Particles too fine to be trapped by elements 58 ar ultimately trapped by secondary filter 54, such that the air discharged at the outlet of blower 56 is particle-free and safe to breath. Blower 56 is deactivated normally when sensor 66 signals that the powder level is high (e.g., the hopper is full), but can also be deactivated manually using the controller switch (as for example, when supply container 67 has run out of powder prior to hopper 50 being full). Note that because of the ability of the hopper to load itself automatically from a large external container, it may itself have only a relatively small capacity.

It might be assumed that activation of blower 56 might not only cause powder to be drawn from container 67 through hose 48, but might also cause powder to be inadvertently drawn from hose 60 and from PDA 44 through hose 60, or for air to bubble up through PDA 44 and hose 60 into hopper 50. However, so long as there is a minimum level of powder within hopper 50, no flow of powder due to the partial vacuum within occurs through the bottom. The reason for this appears to be that the differential pressure associated with the partial vacuum is not sufficient to

lift the weight of the powder in the bottom of hopper 50, hose 60, or PDA 44, nor is any of this powder permeable enough to allow outside air to enter through PDA mesh 45 and bubble up into the hopper (probably conveying with it some powder as well). On the other hand, the differential pressure is sufficient to create a high air flow environment in hose 48, which is at worst only partly filled with powder, and in the vicinity of its open end, causing powder to be drawn from container 67. It is true, however, that when hopper 50 is being filled for the first time with a particular powder and especially if PDA 44 and hose 60 are empty, it is not possible to operate the system exactly as described above because air and powder are in this case likely to be drawn into the hopper through hose 60, rather than strictly through hose 48. There are two solutions to this problem: the first is to transfer a minimum amount of powder into the hopper by scooping or pouring material from a bucket. The second, preferred solution, is to shut off flow through hose 60, either by pinching, or using optional valve 61, in which case loading of all powder can be accomplished using blower 56.

Sensors 66 can be based on a variety of sensing principles known in the art; however, sensors based on measuring electrical capacitance have the advantages of being simple, robust, and free of moving parts. As long as only a small amount of powder adheres to the sensor after immersion in powder, such sensors perform reliably.

Figs. 7 and 8 detail the preferred embodiment configuration and principle of operation of powder collection gutter 71 and related components. Gutter 77 is designed to completely surround bin 68 and is provided with inclined guides 72 which are composed of springy but stiff material such as plastic, and which make intimate contact with the outer walls of bin 68. Located below guides 72 is a continuous trough section 76 which receives powder entering gap 65 when inflatable seal 74 is uninflated. Seal 74 is attached to top plate 70, which is fastened to gutter 71 by four thumbscrews (not shown) inserted through holes 79. When the thumbscrews are removed, plate 70 and seal 74 can be easily removed from gutter to allow access to trough section 76 for

cleaning. Sectional views 73 and 75 are similar, and view 75 is what is shown more clearly in Fig. 8. Vacuum port 77 communicates clockwise with gutter airspace 78 through its entire length, wrapping around bin 68 from the upper righthand corn r where port 77 is located. The hose (not shown) of a vacuum cleaner (not shown) equipped with a high-particle retention filtration system (e.g., including a HEPA filter) and low-velocity blower is attached to the outside of port 77. Airspace 78 is terminated by bulkhead 80, which prevents clockwise airflow when vacuum is applied to port 77. Vents 79 allow entry of outside air when seal 74 is closed.

Excess powder spilling over the rim of bin 68 during layer spreading falls onto guides 72 and through gap between uninflated seal 74 and trough section 76, settling in airspace space 78 formed by trough section 76. Periodically, at a time when a layer is not being spread (e.g., every layer, while the cross-section is being formed), seal 74 is closed by inflating, causing air to enter vents 79 and flow counterclockwise toward port 77, carrying powder in airspace 78 out through port 77 to the vacuum cleaner, from whose canister the excess powder can be recovered. In effect, closing the seal transforms the open gutter into a mere vacuum hose surrounding the bin, through which, it should be clearly evident, powder can be made to flow with great efficiency. After seal 74 has been closed sufficiently long to remove substantially all powder from airspace 78, seal 74 is deflated so as to permit powder to once again pass through gap 65. This deflation may be accomplished passively by simply closing off the flow of inlet gas, and using a high-flow exhaust valve to deflate the seal quickly and allow the spreading of the next layer to begin without delay. Alternately, the gas in the seal may be actively pumped out to achieve a very rapid deflation. The vacuum cleaner may be activated whenever seal 74 is closed; however, it is preferentially left running continuously, so that airborne particulates within the machine's dust chamber are continuously drawn into gap 65 and removed from the chamber by virtue of the filtration system of the vacuum cleaner. Running the vacuum continuously was not practical with the Alpha

gutter, due to high noise level, limited blower lifetime, and high blower cost.

Other means of closing the gap of the gutter to assist in removing the powder within are of course possible. For example, mechanical vanes, shutters, or doors could be moved to cover the gap. Or the gutter itself might move to a position where vanes, shutters, doors, or even the bin wall itself serve to cover the gap.

One means of inflating the gutter seal is to use the exhaust air produced by the gutter vacuum cleaner. For example, the vacuum cleaner could normally be turned off, but while turned on for a brief period, the exhaust air inflates the seal and powder is sucked out. Turning off the vacuum cleaner then allows the seal to open again. A disadvantage to this approach is that the vacuum cleaning does not continuously clean the air of airborne particulates. To get around this, one might run the vacuum continuously, and simply switch the exhaust stream to the inflatable seal when needed, using a valve.

The powder filling and powder collections systems, the former having a supply container, the latter, a container for recovered powder, need not be independent. Indeed, it may be desirable to convey powder from the gutter back into the PDA, perhaps after some processing (e.g., sieving to remove any possible agglomerates or contaminants). The route back to the PDA could be by way of the powder supply container, or may bypass this and proceed directly into the hopper, or may bypass this as well and proceed directly into the PDA.

While the above description contains many specificities, these should not be construed as limitations on the scope of the invention, but rather as an exemplification of one preferred embodiment thereof. Many other variations are possible. Accordingly, the scope of the invention should be determined not by the embodiments herein, but by the appended claims and their legal equivalents.

CLAIMS

What is claimed is:

1. An apparatus for powder handling used in a layerwise additive fabrication process and apparatus, comprising:

dispensing apparatus for dispensing powder into an enclosure adjacent to a layer-spreading means;

collection apparatus for removing and allowing recovery of excess powder not entering the enclosure to be used in forming layers; and

filling apparatus for transferring bulk powder to and filling said dispensing apparatus.

2. Dispensing apparatus for dispensing powder used in a layerwise additive fabrication process and apparatus, comprising:

an enclosure for said powder having an aperture intended for filling with said powder, and a lowermost face having one or more apertures intended for discharging said powder, wherein said aperture is sufficiently small to limit passage of said powder when there is no movement of said enclosure or of said powder;

mechanical excitation means, wherein said excitation means being mechanically coupled to said enclosure whereby a movement is imparted to said enclosure and said powder, causing a controllable rate of discharge of said powder through said aperture.

3. The enclosure according to claim 2, wherein said small aperture is formed by spanning one or more larger apertures in said lowermost face with mesh.

4. The dispensing apparatus according to claim 2, wherein said excitation means generates movement primarily along an axis mostly perpendicular to the plane of said lowermost face, but with a small movement parallel to said plane.

5. The dispensing apparatus according to claim 2, wherein the vibration frequency is in the range of 80-100 Hz.

6. The dispensing apparatus according to claim 2, wherein the vibration amplitude is in the range of 200-600 microns peak-to-peak.

7. The dispensing apparatus according to claim 2, wherein said excitation means is rigidly attached to said enclosure and imparts movement by an inertial reaction force and wherein said enclosure is compliantly supported, whereby movement along an axis mostly perpendicular to said lowermost face, but with a small component parallel to said face is provided.

8. The excitation means according to claim 7, wherein at least one pair of masses are rotationally driven in counter-rotation about axes not coincident with their respective centers of mass, and with the appropriate degree of symmetry, whereby a resultant inertial reaction force along an axis mostly perpendicular to said lowermost face, but with a small component parallel to said face is provided.

9. The masses according to claim 8, wherein adjustment means are provided to adjust said degree of symmetry to achieve maximum discharge uniformity.

10. A method of forming a layer of powder, wherein said powder is discharged, by the dispensing apparatus according to claim 2, within the path of movable powder spreading means.

11. The method according to claim 10, wherein said dispensing apparatus is moved along with said spreading means and the discharge of said powder needed to form said layer occurs during said movement.

12. Collection apparatus for collecting excess powder used in a layerwise additive fabrication process and apparatus, comprising:

one or more gutters adjacent to an exterior surface of a receptacle, said gutters having at least one sufficiently broad opening to permit entry therein of substantially all of the falling material along substantially the entire gutter length, having open ends, and comprising gutter-transforming means, wherein said gutters is able to transform from an open shape, and wherein powder may enter therein, to a closed shape, whereby said opening is substantially closed;

conveying gas;

means for generating flow of conveying gas;

controlling means;

the flow-generating means being connected to at least one of said open ends;

said controlling means activating said gutter-transforming means to change the gutter to a closed shaped, wherein said powder within the gutters are removed by flow of conveying gas through one of said open ends, using minimal flow volume and velocity.

13. The collection apparatus according to claim 12, wherein said conveying gas is air and the flow-generating means is a vacuum-generating apparatus.

14. The collection apparatus according to claim 13, wherein a single gutter is shaped to surround the receptacle on all sides.

15. The gutter-transforming apparatus according to claim 12, comprising a flexible fluid-inflatable structure inflated by pressurizing means, whereby inflation and deflation produce the required changes of shape with minimal moving parts and having high abrasion resistance, as is needed when in contact with abrasive powders.

16. The inflation fluid according to claim 15, wherein said pressurizing means is air.

17. The active element according to claim 15, comprised of an elastomer and wherein said pressurizing means cause an elastic deformation of said element, and wherein said deflation occurs rapidly, permitting the pressurized gas to be exhausted and said element to transform back to its initial unpressurized shape.

18. The collection apparatus according to claim 12, wherein a vacuum is applied to said gutter in said open shape to draw in and extract from the air fine particulates, especially those generated by the fluent medium during said receptacle filling operation.

19. Filling apparatus for filling a dispensing apparatus used in a layerwise additive fabrication process and apparatus, comprising:

a filling apparatus for filling a dispensing apparatus with powder, comprising:

a closed hopper comprising an outlet, vacuum apertures, and an inlet tube;

vacuum-generating means;

an outlet tube;

said vacuum-generating means attached to said vacuum aperture;

said inlet tube being provided with powder from a supply container;

said vacuum-generating means being activated to draw powder from a supply container into said hopper through said inlet aperture;

said outlet tube being attached to said outlet aperture, and conveying by gravity on an as-needed basis, said powder to said dispensing apparatus located substantially below said hopper.

20. The filling apparatus according to claim 19, further comprising powder level sensing means to sense high and low powder levels.

21. The filling apparatus according to claim 20, further comprising control means wherein said vacuum-generating means is controlled by said powder sensing means.

22. The hopper according to claim 19, further comprising air filtering means, whereby said powder is substantially forced to exit via said outlet aperture uniquely, whereby the generation of airborne particulates is avoided.

23. The filling apparatus according to claim 19, adapted for filling a moving dispensing apparatus, further comprising pivoting means allowing tilting of the hopper, and wherein the outlet tube is flexible, whereby bending of the tube due to relative movement of said dispensing apparatus and hopper helps to promote smooth flow of said powder through said outlet tube, whereby the dispensing apparatus is kept substantially full without need for any closed-loop level sensing and metering apparatus.

24. The filling apparatus according to claim 19, wherein the vacuum level produced by said vacuum leveling means is sufficiently high to draw powder into said hopper through the inlet tube, but insufficiently high to disturb a substantial depth of powder in the bottom of said hopper and in its outlet circuit.

Prior Art

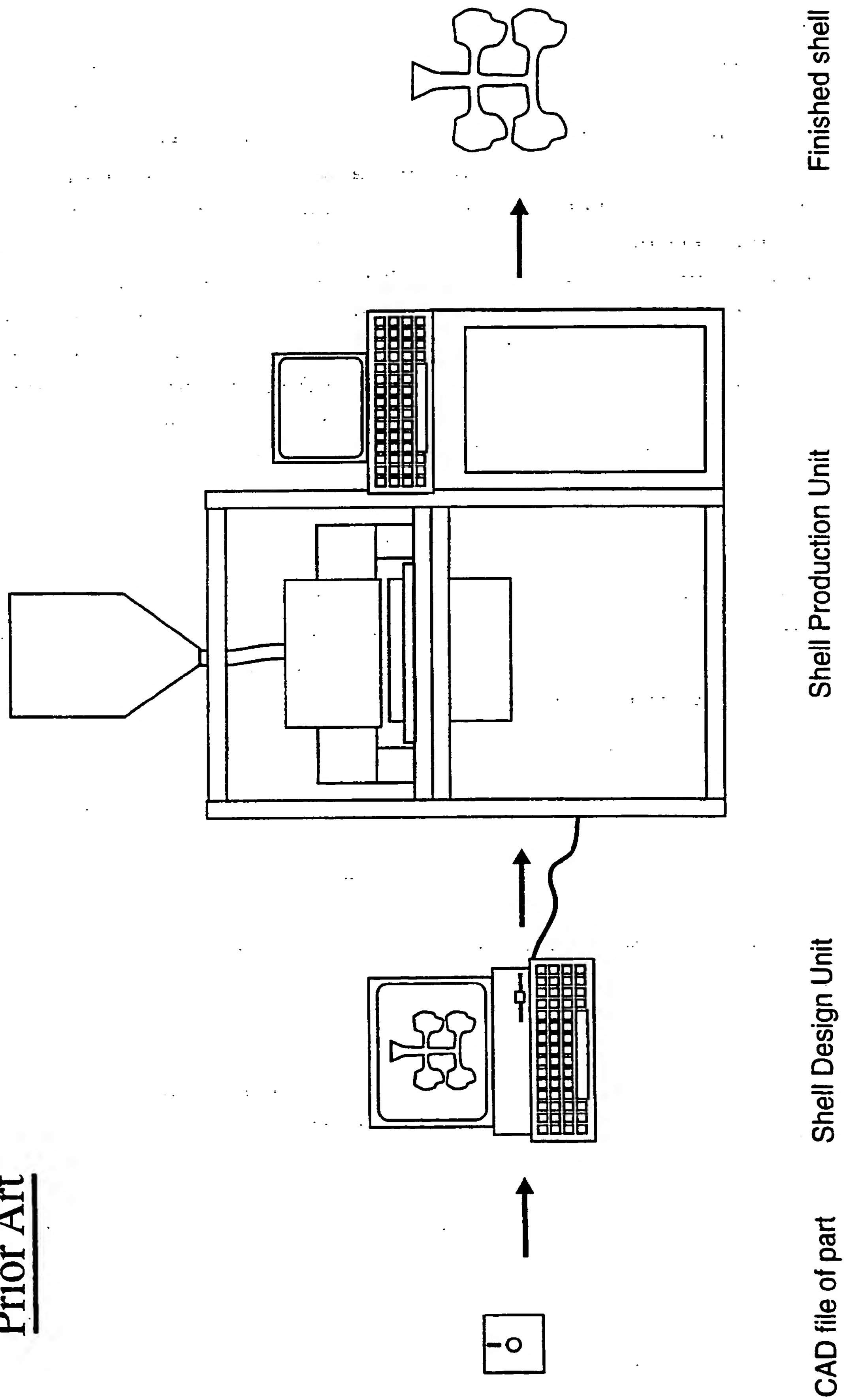


Fig. 1

Prior Art

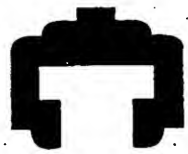


Fig. 2(a)

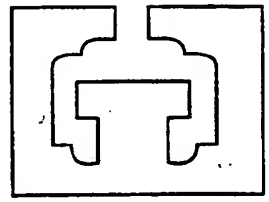


Fig. 2(b)

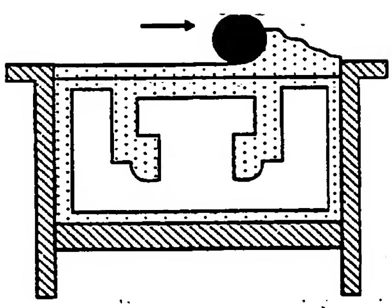


Fig. 2(c)

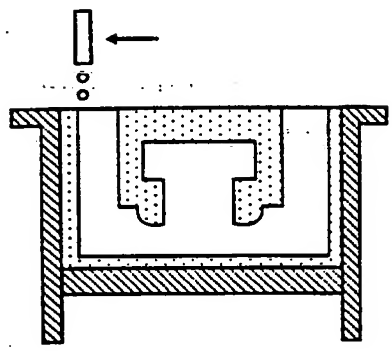


Fig. 2(d)

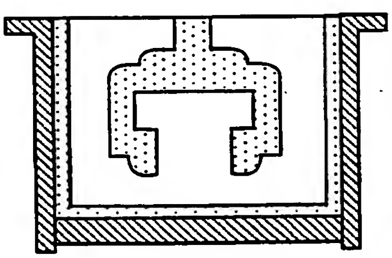


Fig. 2(e)

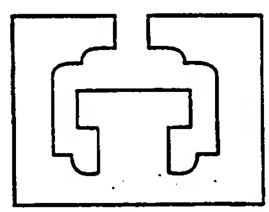


Fig. 2(f)

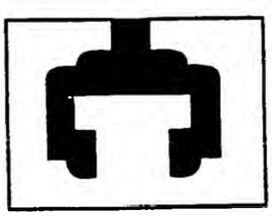


Fig. 2(g)

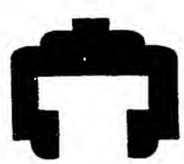


Fig. 2(h)

Prior Art

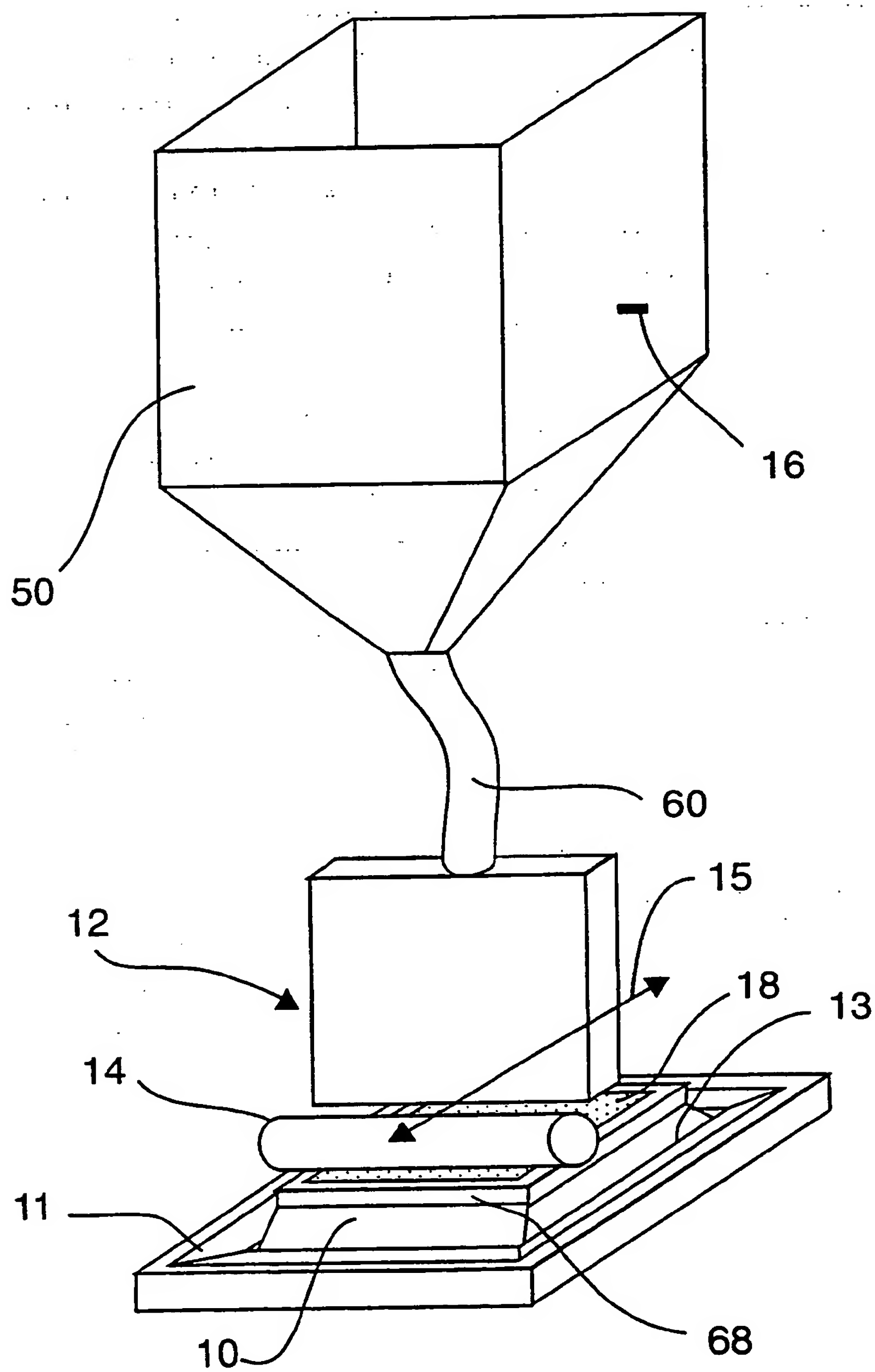


Fig. 3

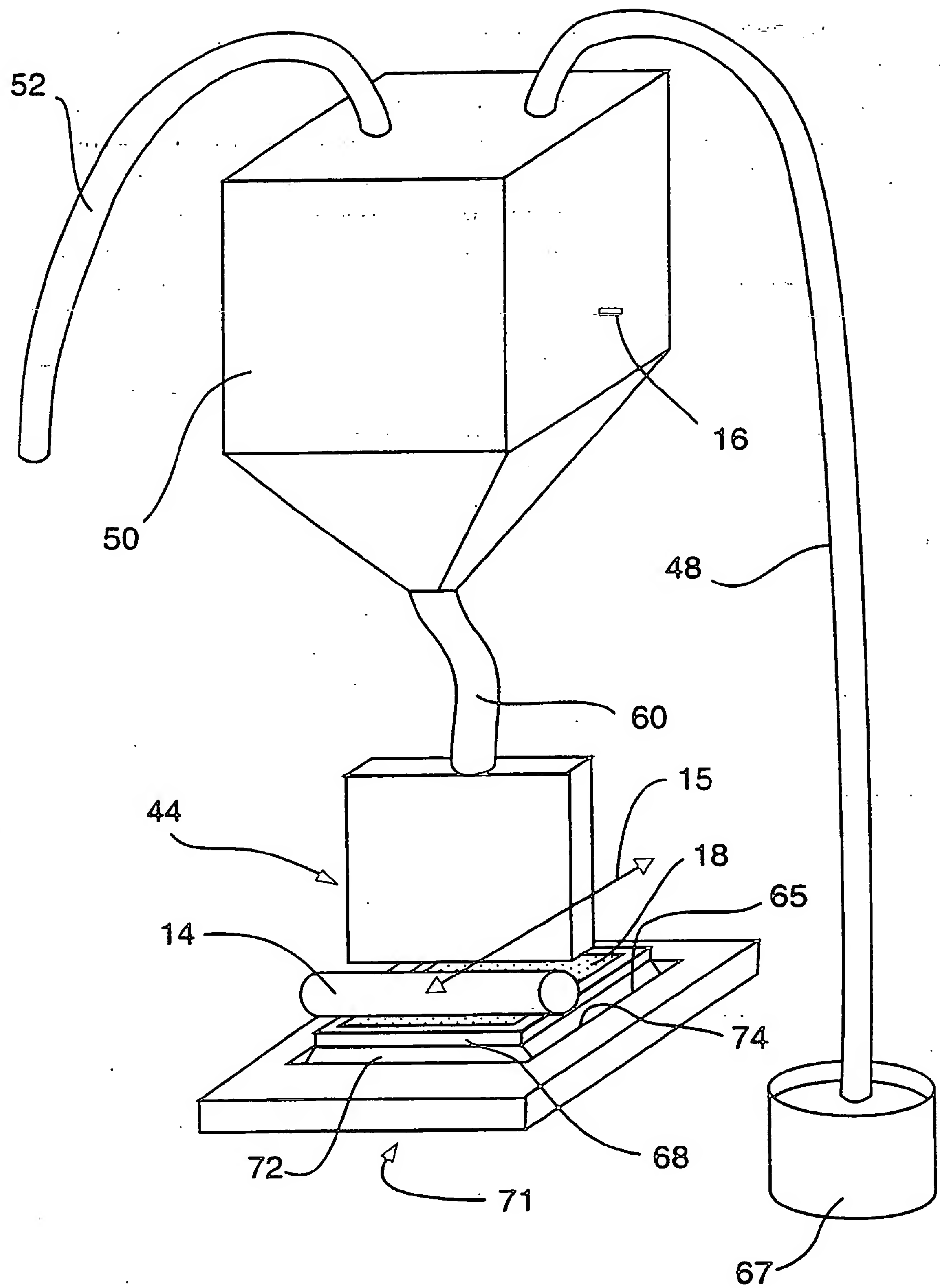


Fig. 4

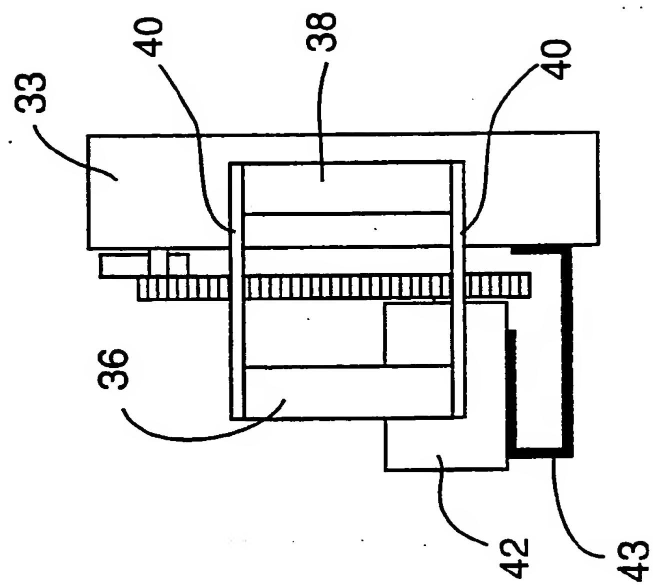


Fig. 5(b)

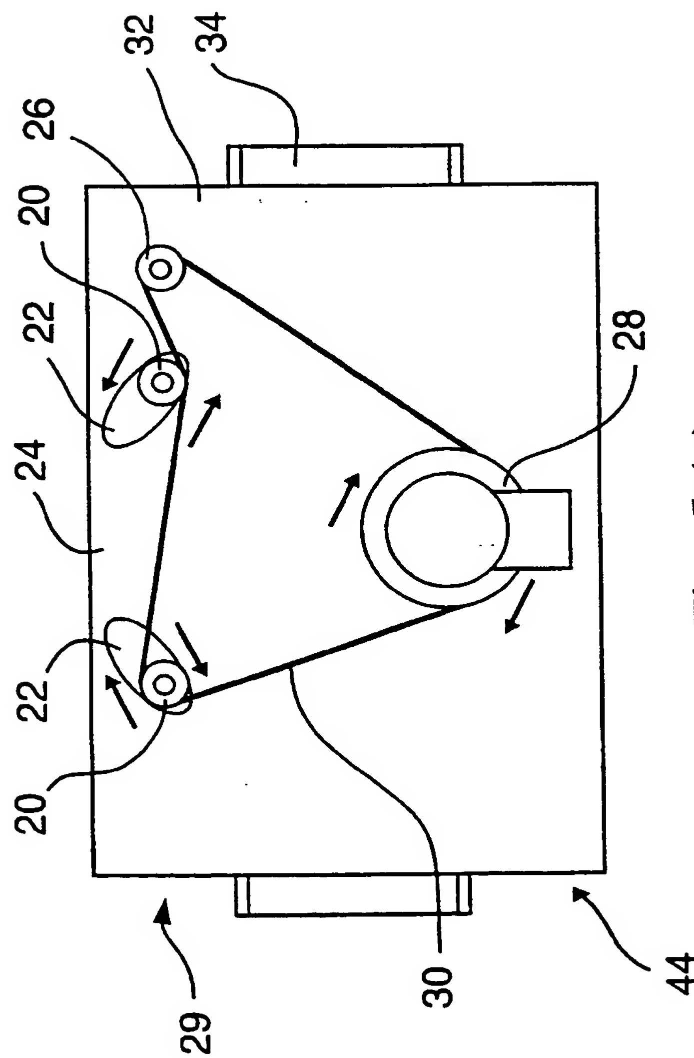


Fig. 5 (a)

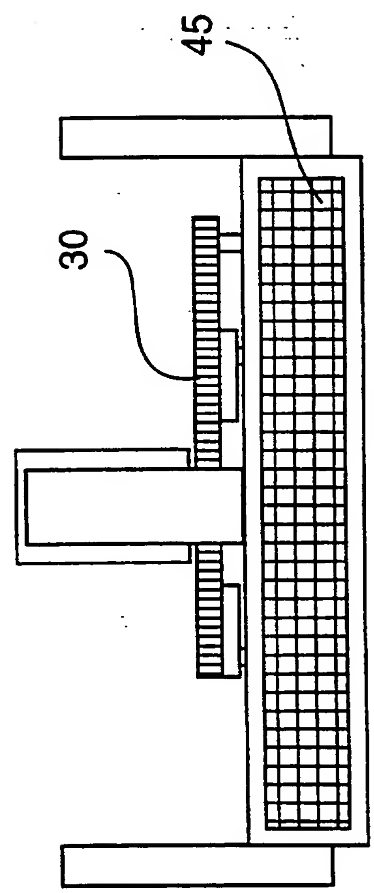


Fig. 5(c)

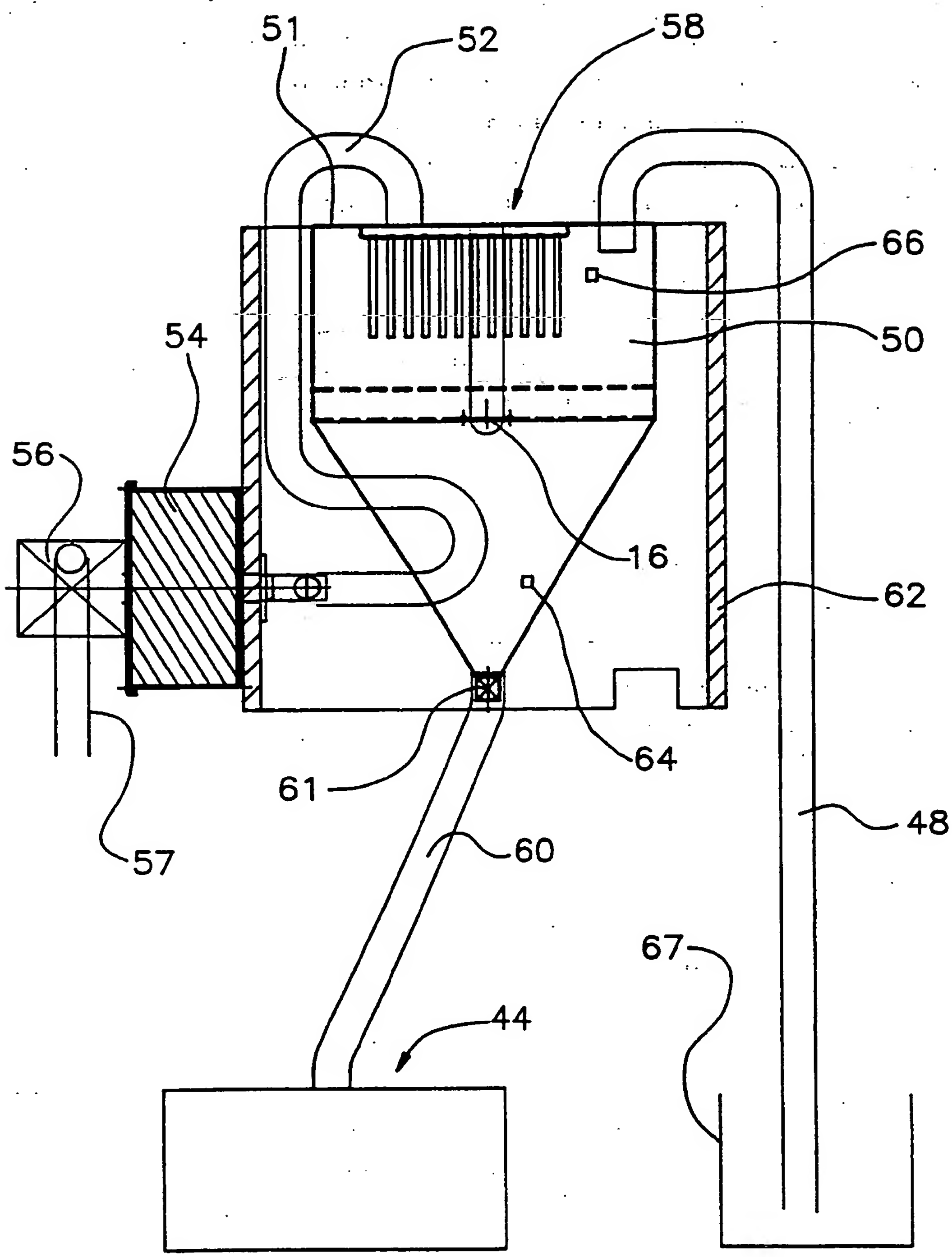


Fig. 6

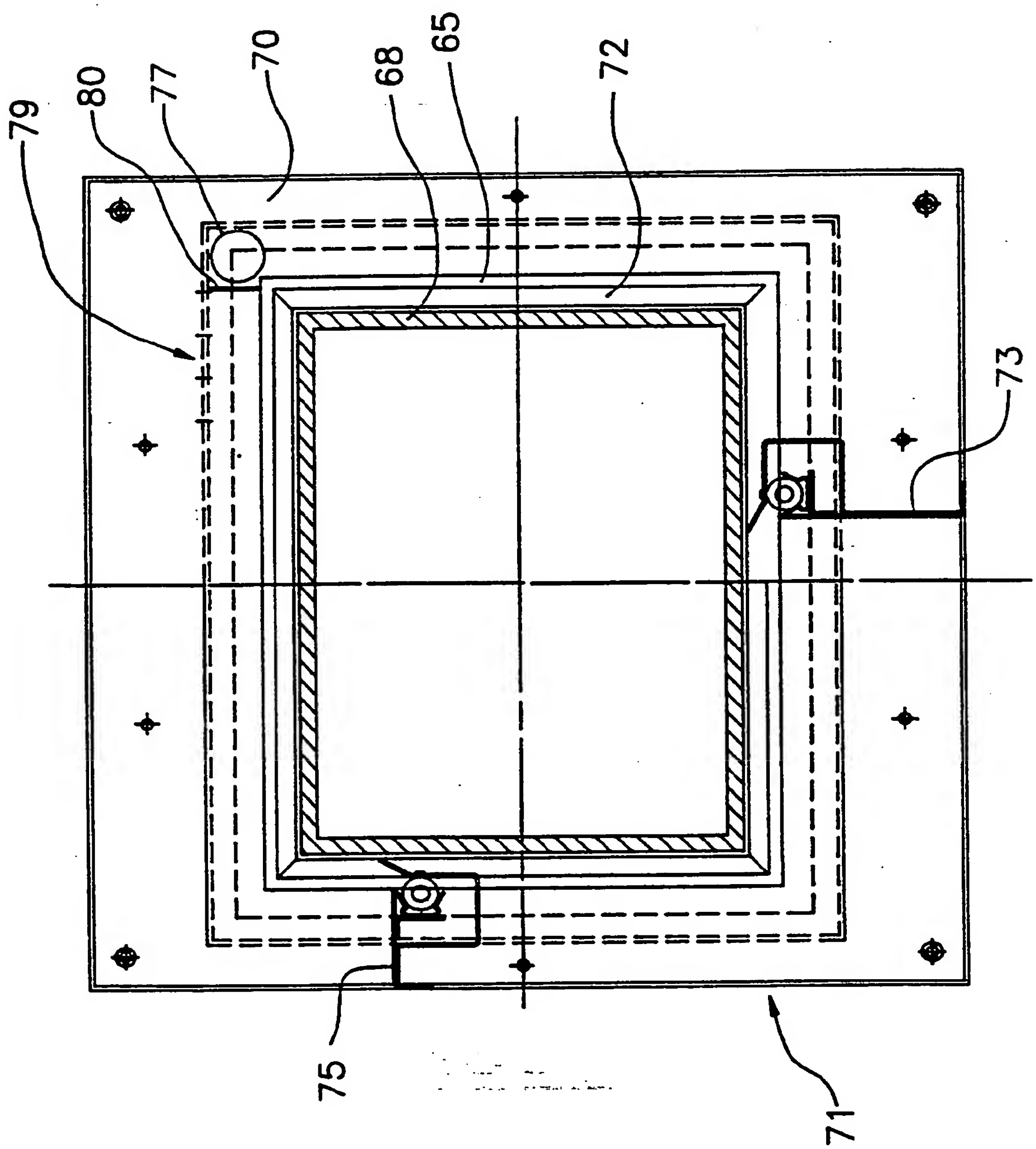


Fig. 7

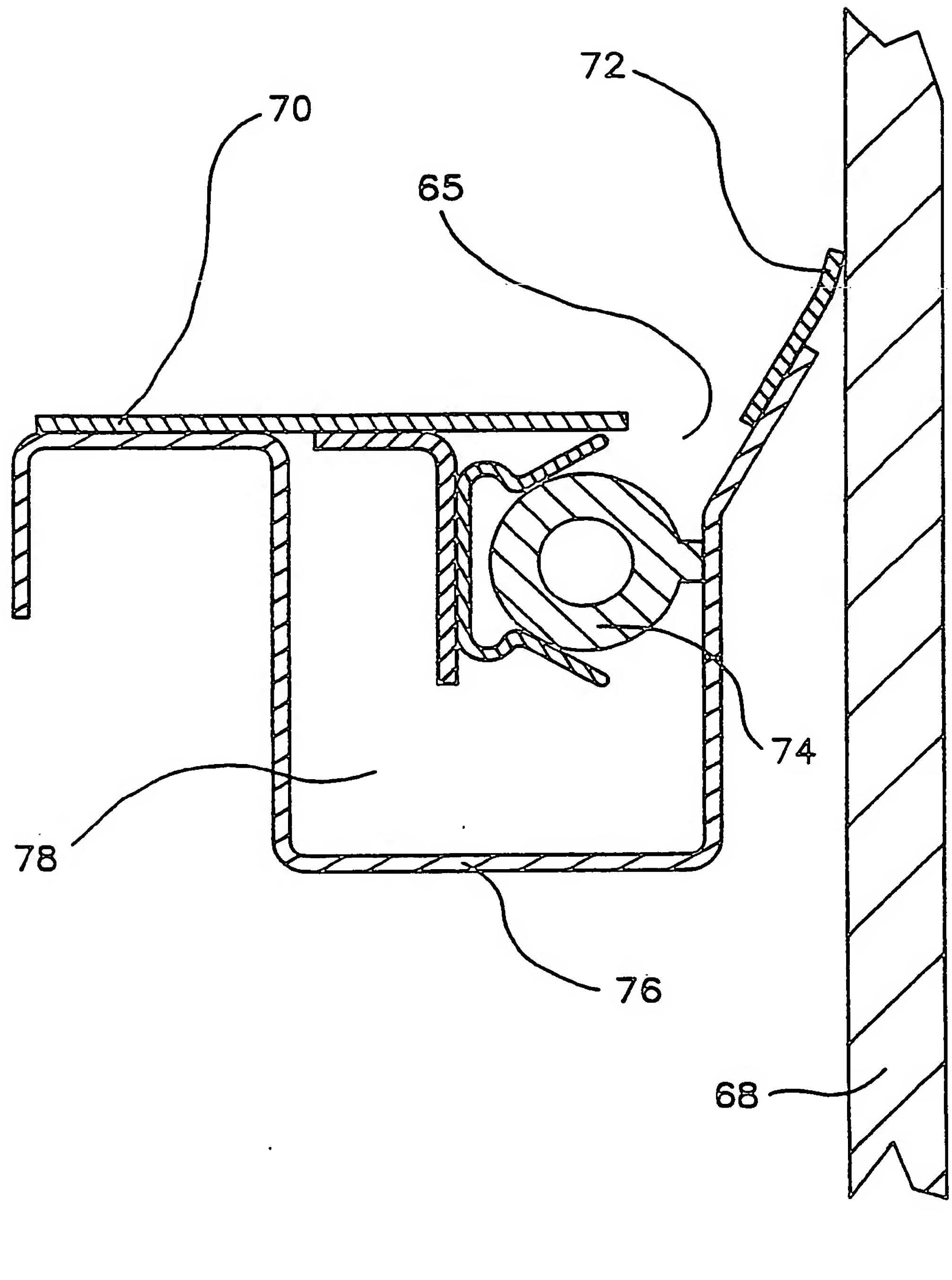


Fig. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US95/07505

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :B65B 1/04, 3/04, 31/00; B05D 1/12
US CL :Please See Extra Sheet.
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 141/18, 86, 123, 126; 427/180, 197, 359, 372.2, 375; 156/62.2; 425/257; 264/113

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X,P	US, A, 5,415,717 (PERNEBORN) 16 MAY 1995, col. 6, lines 16-19	1, 2, 4
X	US, A, 4,011,036 (BICHET) 08 MARCH 1977, col. 5 (lines 41-68) and col. 6 (lines 1-12).	1, 2, 4, 19
X,T ---- Y	US, A, 5,429,788 (RIBBLE ET AL.) 04 JULY 1995, SEE ENTIRE DOCUMENT	1 --------- 2, 4, 7
Y	US, A, 4,106,535 (DAVIS) 15 AUGUST 1978, col. 3, lines 15-22.	2, 4, 7

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 SEPTEMBER 1995	12 OCT 1995

Name and mailing address of the ISA/US	Authorized officer
Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	TIMOTHY L. MAUST H. Leon Merritt
Facsimile No. (703) 305-3230	Telephone No. (703) 308-3390

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US95/07505

A. CLASSIFICATION OF SUBJECT MATTER:
US CL :

141/18, 86, 123, 126; 427/180, 197, 359, 372.2, 375; 156/62.2; 425/257; 264/113

Form PCT/ISA/210 (extra sheet)(July 1992)★